Journal of Memory and Language 92 (2017) 158–169

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Task-dependent motor representations evoked by spatial words: Implications for embodied accounts of word meaning

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ARTICLE INFO

Article history:
Received 18 March 2016
revision received 15 June 2016

Keywords:
Embodied cognition
Spatial representation
Word meaning

ABSTRACT

Embodied accounts contend that word meaning is grounded in sensorimotor representation. In support of this view, research has found rapid motor priming effects on vertical movements for words like *eagle* or *shoe*, which differ as to whether they are typically associated with an up or down spatial direction. These priming effects are held to be the result of motor representations evoked as an obligatory part of understanding the meaning of a word. In a series of experiments, we show that prime words associated with up or down spatial locations produce vertical perturbations in the horizontal movements of a computer mouse, but that these effects are contingent either on directing conscious attention to the spatial meaning of the word, or on the inclusion of the primed spatial direction in the response set, and that this is true even for strongly spatial words such as *up* and *down*. These results show that the motor representations associated with such words are not automatically evoked during reading. We discuss implications for claims that spatial representations reflect our embodied perception of the world.

Introduction

The meaning of spatial prepositions like *above* and *below* can influence the selection of an up/down movement. For example, the word *above* acting as a prime, induces faster and more accurate upward than downward responses, whereas the word *below* yields the opposite result (Ansorge, Khalid, & König, 2013). More surprisingly, analogous results have been reported for words like *bird* and *submarine* that, although not explicitly concerned with spatial location, nonetheless affect speeded responding in an up/down direction (e.g. Dudschig, de la Vega, De Filippis, & Kaup, 2014; Dudschig, Lachmair, de la Vega, De Filippis, & Kaup, 2012; Lebois, Wilson-Mendenhall, & Barsalou, 2015). We will refer to such words for convenience as UP/DOWN words. The evidence suggests that many words, at least under certain task conditions, trigger spatial representations associated with our experiences of objects; birds are often encountered above us in the sky, whereas submarines move below in the depths of the ocean.

Spatial compatibility effects induced by language are often taken as support for the claim that meaning is grounded in sensorimotor representations, including representations dealing with an object's typical location in space. For example, Ansorge, Kiefer, Khalid, Grassl, and König (2010) used a set of six spatial prepositions like *above* and *below*, and two adjectives (*high* and *deep*) as both masked primes and as targets. Subjects were required to indicate by means of an upper or lower keypress made from a neutral starting point whether target words referred to an upward or downward spatial position or direction. Semantic congruency effects on speeded responding were found even though the primes were pre-

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http://dx.doi.org/10.1016/j.jml.2016.06.006
0749-596X/

sented too briefly for conscious report. According to the authors, their findings are consistent with "...mandatory sensorimotor processing of words when accessing their meaning" (p. 303). A similar result was obtained by Dudschig et al. (2014), who found priming effects for subliminally presented UP/DOWN words on the speed and accuracy of upward/downward responses to color cues. The authors concluded that "...language-action interconnections are automatically activated ... (when) ... processing a very wide set of linguistic stimuli, even in paradigms that limit strategic language processing to a minimum" (p. 156).

In contrast, Lebois et al. (2015) found no evidence that UP/DOWN words acting as primes influenced performance when the task simply involved speeded up/down responding to a color cue. Rather, an explicit decision about word meaning was needed to yield spatial priming effects. Because these authors repeatedly failed to find congruency effects under well-defined task conditions that involved no explicit attention to the meaning of words, Lebois et al. rejected the claim that spatial congruency effects are automatic. They argued instead that a variety of conditions might tacitly have increased the accessibility of spatial features in other studies. For example, the requirement to engage in up/down keypress responses to a color cue (e.g. Dudschig et al., 2014) may well have oriented subjects to verticality as a response dimension, establishing a context that dynamically activated the spatial features of words. A version of this idea could even apply when the priming words are presented too quickly for conscious report. Task set influences the way unconscious stimuli are processed (e.g., Ansorge et al., 2010; Kunde, Kiesel, & Hoffmann, 2003), a consideration leading Dudschig et al. (2014) to acknowledge in their study that "... even the mounting of the response apparatus in the vertical dimension might activate specific response codes that ... influenced how the words were unconsciously processed (p. 156)." Lebois et al. (2015) noted that their response apparatus was positioned on the right of the computer screen, a departure from the more conventional position centered along the midline. This spatial arrangement would force subjects to glance back and forth horizontally when producing a response. The need to engage in this left-right orienting may have rendered verticality a less salient dimension, triggered only by instructions to explicitly process the meaning of words.

In this article, we seek to further evaluate the conditions that determine the influence of spatial words on movement in a vertical direction. Our methodological approach reduces the influence of task demands emphasizing up versus down as the intended response, while still allowing us to measure subtle effects of a word on the vertical component of a movement. Consider moving a cursor horizontally on a screen by means of a computer mouse, from a central position to one of two locations placed some distance to the left or right of the starting point. Although the requirement is ostensibly to move the cursor along a horizontal axis, the trajectories will immediately reveal that the movements include a definite vertical component. In general, there are obvious deviations along the vertical axis as the hand moves the cursor horizontally.

Note that, because the mouse lies on the flat surface of the table, an upward movement of the cursor actually requires a forward extension of the arm and a downward movement of the cursor requires flexion of the arm. This introduces a possible complication in that the relationship between the primed spatial direction and the associated motor action is indirect; the up/downward movement of the cursor corresponds to extension and flexion of the arm. We assume, however, that the motor system may directly convert arm movements into a representation of the resulting cursor movement. There is indeed neurophysiological evidence that supports this assumption. Ochiai, Mushiake, and Tanji (2005) projected an image of a monkey's hand onto a computer screen, and required the monkey to move the image to a target location presented at various angles relative to a starting position. In one condition, the image was mirror reversed relative to the monkey's hand, so that the direction of motion on screen was opposite to the actual motion of the hand. Some of the neuron populations in the ventral premotor cortex coded for the direction of image motion, and not the motion of the hand itself. The authors concluded that "...[ventral premotor] neurons play a crucial role in determining which part of the body moves in which direction, at least under conditions in which a visual image of a limb is used to guide limb movements" (p. 929). We assume that a similar principle applies when limb movement is guided by the image of a cursor.

Our methodology is based on the conjecture that under certain task conditions, the extent of the vertical deviation of a horizontal cursor movement should be influenced by the priming of spatial features representing an upward or downward direction. Evidence supports our assumption. Tower-Richardi, Brunyé, Gagnon, Mahoney, and Taylor (2012) had subjects use a computer mouse to move a cursor to one of four rectangular target boxes situated to the left, right, above, and below a central start box. Cued movements were produced in response to the words *up*, *down*, *left* or *right* and the words *north*, *south*, *west* or *east* acted as briefly occurring primes. The word *east* biased vertical target movement trajectories to the right, and *west* biased these trajectories to the left. The word *north* biased the trajectory of horizontal movements upward, whereas *south* biased the horizontal trajectory downward. Additional support for the idea that words can prime movement in a direction orthogonal to a cued trajectory was provided by Zwaan, Van der Stoep, Guadalupe, and Bouwmeester (2012). These authors required subjects standing or seated on a Wii balance board to indicate whether a sentence was sensible or not by moving the board sideways (e.g. left for sensible, right for non-sensible). The sentences implied movement in a forward (e.g., *John bent to tie his shoelaces*) or backward direction (e.g., *John braced himself in the tug of war*). Because the balance board provided spatio-temporal co-ordinates that included forward/backward components of movement, it was possible to determine from the trajectories whether the sentences activated spatial representations consistent with their meaning, even though the task ostensibly involved leaning only to the left or right. Depending on the forward/backward direction implied by the sentences, the sideways trajectory of the response was indeed shifted in an anterior or posterior direction in accordance with the sentence content. Zwaan et al. inferred that understanding the sentences activated a forward or backward direction that was integrated with and altered the trajectory of left/right movements.

Clearly, the meaning of words or sentences can prime a vertical or horizontal component of movement orthogonal to the direction of an intended trajectory. What task conditions, given this evidence, are required for words like *above* and *below*, or UP/DOWN words like *eagle* and *basement* to evoke spatial representations that affect the vertical component of a left- or rightward movement? In Experiment 1, we asked subjects to move a cursor left or right from a central position to a target area, using a computer mouse with direction cued by an arrow pointing to the left or right. Responding was contingent on the prime word being a spatial preposition, such as *up* or *down*; responses were withheld for other prime words. Movement trajectories were clearly altered in a vertical direction. In Experiment 2, when words were passively viewed as primes, no biasing effect was observed. However, when subjects were cued (again by means of an arrow) to make vertically (up/down) as well as horizontally (left/right) directed movements of the cursor (Experiment 3), UP/DOWN words evoked spatial representations that affected horizontal responses, even under passive viewing conditions. We discuss the role of task context in triggering spatial components of meaning that affect ongoing motor activity. In addition, we consider the wider implications of our results for claims about the nature of semantic representations for spatial words.

Experiment 1

In Experiment 1, we looked for evidence that spatial prepositions (e.g. *above*, *below*) and other explicit descriptors of vertical position (e.g. *high*, *low*) can influence the upward/downward component of a horizontally directed movement. The semantics of prepositions dealing with space are highly complex; for example, Tyler and Evans (2003) discussed no less than 15 distinct senses of the word *over* (compare, the *cat jumped over the wall* and *dinner time is over*). Nevertheless, as Tyler and Evans point out, many of these different senses of *over* are directly concerned with or linked to the notion of a focal object being higher than, but within potential contact with, some background element. We assume therefore, as do others, that "...spatial features are central for words whose meanings depend heavily on spatial position" (Lebois et al., 2015, p. 1792), and that this assumption is uncontentious for words like *over*, *under*, *high*, *and low*. More controversial, as we have already observed, is whether explicit attention is needed to the spatial meaning of these words to cause priming effects on the upward/downward component of a horizontally directed movement. Our first step, before turning to this question, was to establish that priming indeed occurs when subjects attend to the directionality of the words while carrying out a cued left/right movement.

Method

Subjects

Forty students at the University of Victoria participated to earn extra credit in an undergraduate psychology course. The experiments reported here were approved by the University of Victoria Human Research Ethics Committee.

Materials and procedure

Subjects performed a go/no-go task requiring them to move a mouse cursor from the center of a computer screen to one of two circular target regions on the left and right sides. Trials began with the presentation of a word cue selected from one of eight spatial prepositions connoting up or down (e.g. *up*, *down*, *above*, *below*) or eight abstract nouns (e.g. *justice*, *crime*). A complete listing of the words used for each experiment can be found in Appendix A. Word cues were presented for 50 ms in a lowercase, monospace font, and were followed by a 100 ms blank screen, after which an arrow cue appeared in the center of the screen, alongside two circular target regions on the left and right sides. Each target region subtended a visual angle of approximately 2°, and was separated from the center of the screen by an angle of 16°. Subjects were seated approximately 60 cm away from the computer screen, and performed the task using their dominant hand. Moving the cursor from the center of the screen to the target region required moving the hand approximately 28 cm on the computer desk. Subjects were instructed to move the cursor to the corresponding target region if the word was directional (*go* trial), and to simply click the left mouse button otherwise (*no-go* trial). The arrow cue remained in view until the cursor entered one of the target regions. After reaching the target region, a circular target appeared in the center of screen, and subjects were required to move the cursor back to the center and click the mouse button to begin the next trial. Prior to performing the task, subjects were shown a list of the cue words and instructed that it was not necessary to memorize them, but to simply note what is meant by "directional" and "non-directional".

The task consisted of 40 practice and 320 experimental trials. The design of the experiment was fully counterbalanced, so that each combination of cue word and response direction occurred equally often. The experiment was programmed using the Psychophysics Toolbox extension for Matlab (Brainard, 1997), and was performed on a 27-in. Apple iMac. The position of the cursor on the screen was captured at 60 Hz during the movement phase of the task. Cursor speed was set to its lowest setting, and cursor acceleration was disabled. Note that the 60-Hz refresh rate of the iMac monitor implies a screen refresh interval of 16.67 ms, which allows for the precise specification of a 50-ms cue word duration ($3 * 16.67$).

Results and discussion

All data handling and preprocessing were done using the R statistical language (R Core Team, 2013), and Bayesian models for data analysis were fit using Stan 2.7

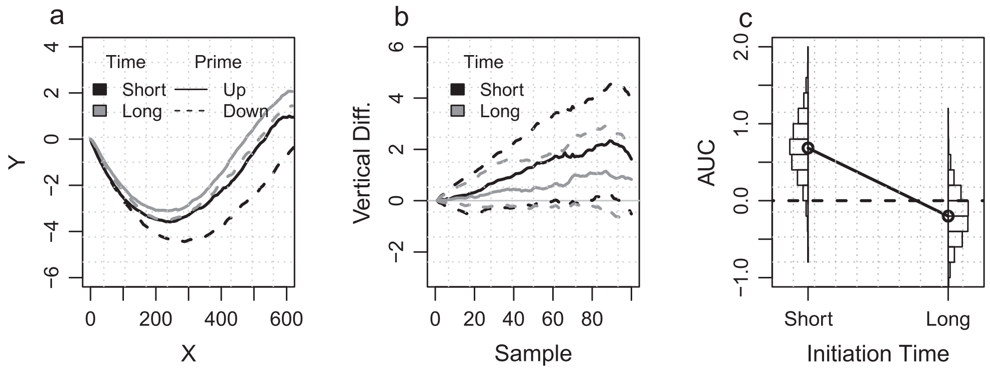

Fig. 1. Analysis of mouse trajectories for Experiment 1. (a) Mean X-Y trajectories (measured in screen pixels) for up and down prime conditions as a function of initiation time (based on a median split of movement initiation times). (b) Vertical difference between trajectories (measured in screen pixels) in up and down prime conditions (up-down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean area under the curve (AUC) of the difference trajectories. The AUC effect for short initiation times is positive with probability .97.

(Stan Development Team, 2015). We defined the beginning of the trajectory to be the instant that cursor velocity exceeded zero, and the end to be the instant that the cursor reached one of the two target regions. Each trajectory was then resampled to 100 equally spaced time points using linear interpolation. Trajectories were not smoothed or filtered, as they were sampled without noise, and the low cursor velocity naturally resulted in smooth trajectories. Trajectories were placed in a coordinate system by specifying the origin (0,0) to be the center of the screen.

Incorrect trials (those in which the cursor entered the incorrect target region), as well as trials with movement initiation times greater than 3 standard deviations above the mean for each subject, were excluded from analysis. In addition, we excluded trials in which the trajectory length was greater than 1.5 times the distance from the center of the screen to the target region. This was done because several trials exhibited wandering behavior, in which the cursor seemed to travel back and forth across the screen. The 1.5 threshold was selected arbitrarily to exclude the most severe wandering behavior, while being conservative enough to retain the vast majority of trials. In total, fewer than 5% of trials were excluded for each subject.

Previous studies have reported stimulus-response compatibility effects even when stimulus and response sets vary along orthogonal dimensions (so-called *orthogonal* stimulus-response compatibility effects; see Lippa & Adam, 2001). For example, an up-right, down-left advantage is often observed in Simon tasks (Cho & Proctor, 2003). For this reason, we performed a preliminary analysis in order to rule out differential effects of spatial words on leftward and rightward responses. We found no evidence of such effects, and indeed leftward and rightward trajectories were highly similar, and so we collapsed both response conditions together by mirroring leftward responses along the *y*-axis.

An additional caveat is that priming effects may preferentially affect fast or slow responses (Khalid & Ansorge, 2013; Ridderinkhof, 2002). According to Kinoshita and Hunt (2008), response activation driven by word meaning is typically greater for trials with faster rather than slower reaction times (see also Ansorge et al., 2013). Because we were measuring the impact of a word cue on the trajectory of a response, we anticipated that more pronounced effects would occur for responses initiated with shorter delays. Therefore, we conducted a median split of the response trajectories based on movement initiation time. The split was applied within each word-cue condition for each subject. In this and subsequent experiments, all analyses are reported separately for trials with short versus long initiation times.

Mean trajectories for each initiation-time category and word-cue condition are presented in Fig. 1a. For each trajectory, we computed bootstrapped 95% confidence bands using the subjects' mean trajectories. We also computed difference trajectories for each initiation-time category by subtracting the mean trajectory for downward cue words from the mean trajectory for upward cue words (Fig. 1b). For each difference trajectory, we summarized the vertical difference between word-cue conditions by integrating the difference trajectories using the trapezoid approximation (denoted by AUC, for *Area Under the Curve*). The mean AUC for each difference trajectory, estimated by fitting a *t*-distribution to the subject values, and posterior distributions are presented in Fig. 1c. A complete description of the Bayesian model used to obtain the posterior distributions is provided in Appendix B.

Our analysis revealed reliably higher *y*-coordinate values (indicating a more upward going trajectory) for responses in the upward cue condition than in the downward cue condition. This effect was observed only in responses with a short initiation time. It is likely that attending to the spatial connotation of the cue words led to the activation of a corresponding spatial representation. The resulting compatibility or interference with the required response produced the observed influence on trajectories with short initiation times, but was resolved before the execution of a slower response.

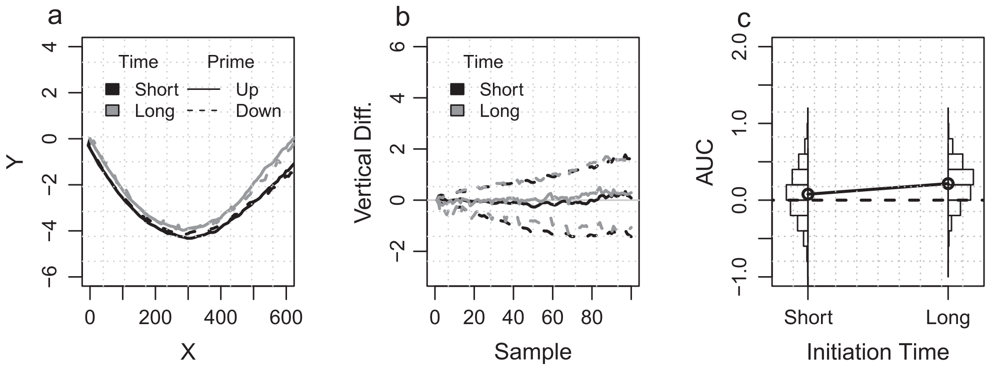

Fig. 2. Analysis of mouse trajectories for Experiment 2a. (a) Mean X-Y trajectories (measured in screen pixels) for up and down prime conditions as a function of initiation time (based on a median split of movement initiation times). (b) Vertical difference between trajectories (measured in screen pixels) in up and down prime condition (up-down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories.

Experiment 2

The results of the previous experiment suggest that (vertical) spatial primes can, under certain conditions, produce perturbations in a horizontal trajectory, and that our method is sensitive to such effects. We turn now to the question of the conditions under which these effects appear. In the previous experiment, conscious attention was drawn to the spatial meaning of the prime words by requiring subjects to classify them as either *directional* or *non-directional*. In contrast, an embodied account that holds that the motor representations evoked by spatial words are an obligatory part of their meaning (e.g., Ansorge et al., 2010; Dudschig et al., 2014), would predict similar effects even under passive viewing. Such effects have indeed been observed for other stimuli; for example, Kuhn and Kingstone (2009) found that arrows perturb the direction of eye movement under passive viewing conditions. Similarly, Hermens and Walker (2010) find that passively viewed arrows, pointing left or right, produce deviations in eye movement trajectories directed toward targets above or below fixation.

We wished to determine whether similar effects could be observed in response to a passively viewed spatial preposition, or whether such effects are dependent on conscious attention to the spatial meaning of the word, as in Experiment 1. We addressed this question through a pair of experiments requiring subjects to generate horizontal responses to an arrow cue, preceded by a word prime. The key difference between the following experiments and Experiment 1 is that subjects were instructed to ignore the prime word and respond to the arrow on all trials. In Experiment 2a, we use prime words adapted from Dudschig et al. (2014), consisting of words such as *mountain* and *shoe*, which are typically associated with an up or down spatial direction. In Experiment 2b, we use the spatial prepositions described in Experiment 1. Note that, although prime words are associated with up or down spatial directions, the task itself requires only horizontal movements. This design, in contrast to the design of Dudschig et al. (2014), eliminates the possibility that priming effects are due to a response set requiring the generation of vertical responses.

Method

Subjects

Eighty students drawn from the same source as in Experiment 1 were tested; half participated in each version of the experiment.

Materials and procedure

The procedure for Experiments 2a and 2b was identical to that of Experiment 1, with the exception that the prime words were passively viewed, and subjects were required to respond on every trial. The prime words in Experiment 2a were adapted from Dudschig et al. (2014), and consisted of words such as *eagle* and *shoe*, which are typically associated with an up or down spatial direction. In total, 10 UP and 10 DOWN words were used. The full list of items is shown in Appendix A. In Experiment 2b, the prime words were identical to the directional primes used in Experiment 1. The experiments each consisted of 40 practice and 320 critical trials, with all combinations of prime word and spatial direction occurring equally often.

Results and discussion

Data were analyzed identically to Experiment 1. Mean and difference trajectories for Experiment 2a are reported in Fig. 2a and b, and posterior distributions for the AUC are reported in Fig. 2c. Results for Experiment 2b are presented in Fig. 3.

We found no evidence for an effect of prime condition on AUC for either short or long initiation times, suggesting that passive viewing is not sufficient to produce spatial representations associated with up or down spatial directions, even with strongly spatial words such as *up* or *down*. These results stand in conflict with results obtained by Tower-Richardi et al. (2012), who found that the words *north*, *south*, *east* and *west* induced perturbations of a computer mouse under passive viewing.

A crucial difference between our experiment and Tower-Richardi et al. (2012) is that, in our Experiment 2, no cued up/down movements of the mouse cursor to vertically displaced targets were required. By contrast, Tower-Richardi et al. included cued movements to targets

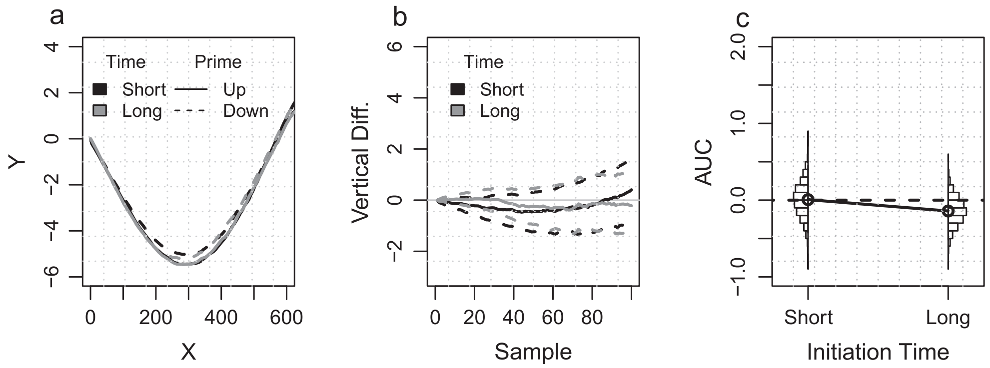

Fig. 3. Analysis of mouse trajectories for Experiment 2b. (a) Mean X-Y trajectories (measured in screen pixels) for up and down prime conditions as a function of initiation time (based on a median split of movement initiation times). (b) Vertical difference between trajectories (measured in screen pixels) in up and down prime condition (up-down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories.

in an up/down as well as a left/right direction. There is evidence that preparing to engage in a task emphasizing up versus down yields greater activation of stimulus and response features coding for verticality (Meiran, Chorev, & Sapir, 2000). We conjecture that the intention to generate cursor movements in an up/down direction is responsible for the evocation of spatial representations to passively viewed UP/DOWN words. This possibility would stand in contrast to the assumption, raised by some embodied accounts, that the evocation of such spatial priming effects is obligatory. If our conjecture is valid, then the requirement to generate vertical cursor movements should induce priming effects from UP/DOWN words, even under passive viewing conditions. We tested this possibility in Experiment 3.

Experiment 3

We conducted a modified version of Experiment 2a in which subjects were cued to move in all four cardinal directions (*up*, *down*, *left*, and *right*). If the inclusion of the vertical dimension in the response set is sufficient to elicit spatial representations from UP/DOWN words, we should observe vertical perturbations of left/right trajectories similar to those observed in Experiment 1. Additionally, we would expect to see an influence of UP/DOWN words on the initiation times for vertical movements, similar to previously reported effects of passively viewed words on response times (e.g., Dudschig et al., 2014).

Method

Subjects

Forty students at the University of Victoria participated to earn extra credit in an undergraduate psychology course.

Materials and procedure

The procedure for Experiment 3 was identical to that of Experiment 2a, with the exception that subjects were cued to move in all four cardinal directions (up, down, left, and right). Two additional target regions were added at the top and bottom of the computer screen at the same distance from fixation as the left/right targets. Similar to Experiment 2a, subjects were cued to move the cursor to one of the four target regions by an arrow. All four movements were cued equally often across 40 practice and 360 critical trials. The two types of prime words (connoting up or down locations) were presented equally often with each of the four directional cues.

Results and discussion

We examined the initiation times of vertical movements in response to UP/DOWN prime words. Fig. 4 displays the mean initiation times for congruent and incongruent responses in each prime condition. As the motor priming effects observed in Experiment 1 were observed only for trials with the shortest initiation times, up/down initiation times were analyzed after performing a median split. We generated mean estimates and highest density intervals by fitting a normal distribution to the subjects' mean congruency effects (mean congruent trial minus mean incongruent trial) with a non-informative $N(0,100)$ prior on the mean and a weakly informative Cauchy(0,15) prior on the variance. The resulting congruency effect on vertical movements was −6.2 ms (95% highest posterior density interval = [−9.9, −2.1]) for short initiation times, and for long initiation times the effect was −3.1 ms (95% highest posterior density interval = [−8.4,2.8]), indicating that the priming effect is rather short-lived and has begun to decay during the preparation or execution of the slower responses. Nevertheless, we have a clear replication of previous reports that passively viewed words connoting up or down directions induce spatial priming effects on vertical movements.

We analyzed horizontal trajectories using the procedure described for Experiment 1. Mean and difference trajectories, as well as an analysis of the AUC, are presented in Fig. 5. The results provide strong evidence of a motor priming effect of UP/DOWN words in responses with short initiation times, in which trajectories primed by UP words

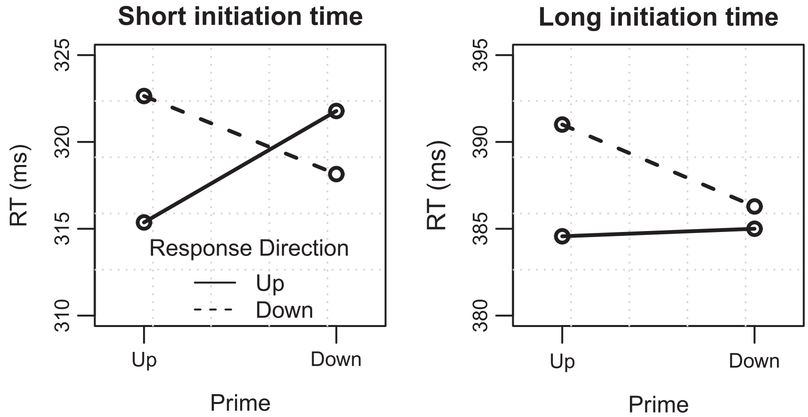

Fig. 4. Mean response initiation time for upward and downward responses in each prime condition. Initiation times were categorized as either short or long based on a median split.

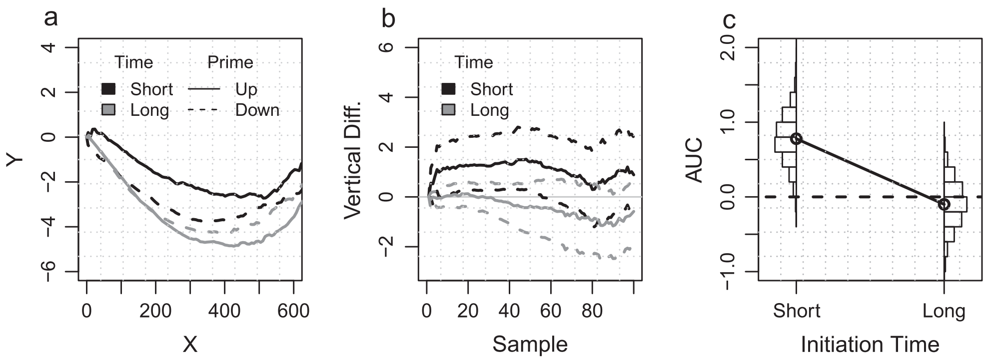

Fig. 5. Analysis of mouse trajectories for Experiment 3. (a) Mean X-Y trajectories (measured in screen pixels) for up and down prime conditions as a function of initiation time (based on a median split of movement initiation times). (b) Vertical difference between trajectories (measured in screen pixels) in up and down prime conditions (up-down). Dashed lines are bootstrapped 95% confidence bands. (c) Posterior distributions for the mean AUC of the difference trajectories. The AUC effect for short initiation times is positive with probability .99.

were consistently higher on the vertical axis than trajectories primed by DOWN words.

These results confirm that the requirement to make vertical cursor movements is sufficient to evoke a spatial representation from words like *eagle* and *shoe*, resulting in motor activation which alters the trajectory of horizontal movements. These effects are readily accounted for by the assumption that action representations are guided by attentional processes induced by task set. For example, according to the principle of intentional weighting (Memelink & Hommel, 2013), forming an intention to engage in an up/down movement automatically increases the weight of the vertical dimension. Thus, asking subjects to carry out up/down cursor movements, will automatically render relevant the perceptual dimension of verticality, which then becomes active in the processing of the word primes. A related account proposed by Ansorge and Wühr (2004) emphasizes the weighting of response codes based on task demands. According to this account, the requirement to discriminate between up and down as response features will automatically weight these features and match them to corresponding stimulus codes. Both these accounts would imply that the task of engaging in up/down movements can trigger semantic features of a word that pertain to the vertical dimension, even on trials cueing a left/right response. Note that on any given trial, the computer screen includes target regions that afford vertical movements, and the prime words themselves are associated with spatial representations that include a vertical dimension, triggered on previous trials requiring vertical responses. Thus, even on trials requiring a left/right movement, there are cues that enable an effect of the vertical dimension on horizontal trajectories. For a similar example of these effects, see Eder, Rothermund, and Proctor (2010), who found that intentional acts of approach and avoidance in an evaluation task influence the involuntary activation of approach and avoidance tendencies even when stimulus valence is irrelevant.

General discussion

Defining the background conditions that allow words like *above*, *below*, *eagle*, and *worm* to prime up/down movements is important if we are to better understand the nature of the spatial representations triggered during semantic access. According to some researchers (e.g., Ansorge et al., 2010; Dudschig et al., 2014), the meaning of spatial words necessarily triggers sensorimotor representations. A word like *up* should therefore exert an obligatory impact on vertical movement even under passive viewing conditions, much like the correspondence effects automatically induced by an arrow pointing in a particular direction (Kuhn & Kingstone, 2009). A rival claim is that task context and the subject's intentions play an important role in evoking priming effects. As a number of authors have noted (Dudschig et al., 2014; Lebois et al., 2015; Thornton, Loetscher, Yates, & Nicholls, 2013), assessing the impact of spatial words on movements generally involves the arrangement of response keys along a vertical axis. This cue, along with the requirement to respond vertically (Ansorge & Wühr, 2004; Memelink & Hommel, 2013), may inevitably draw attention to the spatial features of words associated with an up/down direction.

We wished to eliminate task demands and response options that emphasize up versus down as a contributing factor to the priming effect of a spatial word on vertical movements. At the same time, because compatibility effects require a degree of overlap between stimulus and response dimensions (Ansorge & Wühr, 2004; Kornblum, Hasbroucq, & Osman, 1990), any task must include a vertical feature component that can potentially be affected by a word acting as a prime. Our approach required speeded movements of a cursor by means of a computer mouse, directed left- or rightward from a central location. Given the nature of cursor movements, proprioceptive feedback in this task comprises a mixture of both left/right and up/-down sensations. Although task context (and the subject's intentional set) would determine that this feedback is categorized as a left- or rightward response, it remains possible that spatial words can increase the activation of vertical feature codes, thereby altering the shape of the movement trajectory.

Both theory and prior evidence support this background assumption. According to a recent computational model of the interaction between perception, action, and task goals, feature dimensions can generate concurrently active but competing stimulus-response mappings (e.g., left/right and forward/backward), even though the task instructions favor one mapping over another (Haazebroek, Van Dantzig, & Hommel, 2013). In addition, the trajectory of left/right movements can indeed be modulated by words or sentences acting as primes that imply an up/down (Tower-Richardi et al., 2012) or forward/backward direction (Zwaan et al., 2012).

We validated our methodological approach in Experiment 1 by requiring subjects to carry out a speeded go/no-go task involving left/right cursor movements primed by spatial prepositions denoting an up/down direction. Attention to the meaning of each prime was ensured by requiring subjects to respond only if the prime was a directional word (abstract words served as the no-go items). We observed consistently higher *y*-axis values (indicating a more upwardly oriented trajectory) for horizontal cursor movements primed by words denoting an upward compared to a downward direction. This effect appeared only for responses with short initiation times.

The next question was whether the spatial representations evoked by words are obligatory. If so, cursor trajectories should be affected even when subjects are merely instructed to passively view each prime before responding to an arrow cue. We know that other spatial cues do indeed exert this kind of obligatory influence on components of movement that are orthogonal to an intended direction. For example, eye movements to a target above or below fixation deviate away from the direction indicated by centrally presented arrows pointing to the left or right, even when the arrows merely serve as passive distractors (Hermens & Walker, 2010). Our results indicate that the spatial representations evoked by words do not show this degree of automaticity. Under passive viewing conditions the trajectory of cued left/right movements is unaffected by spatial prepositions, or by UP/DOWN words.

As we have seen, priming effects on left/right movement trajectories occur when attention is explicitly directed to a word's spatial meaning. In addition, however, the task of carrying out vertical movements is itself sufficient to induce priming effects even if words are just passively viewed. In Experiment 3, the initiation time of up/down cursor movements was affected by spatial words as passive primes, consistent with previous work reporting a similar effect on cued vertical movements (Dudschig et al., 2012, 2014). Furthermore, the spatial features of passively viewed words affected left/right cursor movements when up/down movements were included in the response set. Left/right movement trajectories primed by a word like *eagle* were higher on the vertical axis than trajectories primed by a word like *submarine*.

Clearly, passively viewed words influenced horizontal trajectories, despite the fact that the intention to produce a left/right movement does not place any emphasis on verticality. For this priming effect to occur, however, subjects must also engage in up/down movements of some kind. We can distinguish two possible reasons for this constraint. One possibility denies any automatic status to the spatial representations evoked by words. Instead, it is assumed that the task of carrying out vertical movements explicitly draws subjects' attention to a word's spatial constituents.

The alternative possibility, which we favor, is that the requirement to engage in up/down movements enhances the weighting of verticality as a dimension or of vertical response features (Ansorge & Wühr, 2004; Memelink & Hommel, 2013). We note that intrinsic to left/right cursor movements are deviations of the intended trajectory in an up/down direction. Accordingly, we suggest that up/-down features continue to remain active and can be influenced by spatial words so as to perturb the vertical component of horizontal trajectories. Although the vertical dimension would not receive a high intentional weight for left/right cursor movements, Lavender and Hommel (2007) note that the weighting of a task-irrelevant dimension need not fall to zero. Indeed, these authors suggest that "...the more a dimension is directly or indirectly related to the task goal, or its interpretation by the subject, the more weight its codes will carry" (p. 1291). An analogous influence of persistent effects induced by task set and afforded context is discussed by Ansorge and Wühr.

For a number of reasons, we believe that the evocation of a word's spatial features is partially automatic, even though UP/DOWN words and spatial prepositions do not have the same kind of obligatory impact on the trajectory of left/right movements as does an arrow on the trajectory of eye movements (Hermens & Walker, 2010). First, we note that spatial words can prime up/down movements even when presented too briefly for conscious identification (Ansorge et al., 2010; Dudschig et al., 2014), a result consistent with the view that priming effects can occur without the contribution of strategic attention to meaning. A second point against the notion that priming effects are the result of explicit attention is that in Experiment 3, under passive viewing conditions, up/down movements yielded congruency effects on movement initiation time that were stronger when subjects made faster responses. Priming effects driven by attention to the semantic category of a word (including, presumably, the category up versus down) do not vary with the speed of responding (Kinoshita & Hunt, 2008). By contrast, motor priming based on word meaning is greater for faster than slower responses (see also Ansorge et al., 2013, for confirmatory evidence). We infer, given this evidence, that UP/DOWN words directly induce motor rather than semantic priming effects on the initiation time of up/down responses in Experiment 3.

A third reason in favor of the claim that intending to move up or down automatically triggers the spatial features of UP/DOWN words is the following. It does not appear to be the case that under passive viewing conditions, motor intentions are sufficient to induce priming for just any kind of word associated with up/down features. For example, emotionally valenced words, despite their linkage to vertical features (e.g. *elation* → up, *despair* → down), do not, in general, prime up/down movements unless subjects explicitly attend to or base their responses on positive versus negative affect (e.g. Rotteveel & Phaf, 2004). Indeed, in a recent meta-analysis of the literature, Phaf, Mohr, Rotteveel, and Wicherts (2014) concluded that: "A consistent finding across all analyses was a non-significant overall effect when instructions did not require conscious evaluation of the affective valence of stimuli. ...In general, there seems to be little evidence for a direct or automatic link between affective information processing and arm flexion and extension, irrespective of whether the movements are made in the horizontal or vertical direction" (p. 13). One interesting exception is provided by Dudschig, de la Vega, and Kaup (2015), who found evidence for priming of up/down responses by a subset of valence words associated with body postures (e.g. *proud* → upright, *sadness* → slouched), even when no valence evaluation was necessary. These words, by virtue of their embodied association with vertical space, may not require deliberate evaluation in order to evoke up/down spatial features. In contrast, valence words unrelated to body posture (e.g. *love* and *hate*) produced no such effects.

The available evidence gives rise to a partial taxonomy of stimuli, indexed by the task conditions that induce spatial priming effects on motor responses. Recall the three task conditions described in the experiments reported above: A stimulus presented as a passive distractor, a stimulus whose spatial meaning is consciously attended to, and a stimulus whose spatial dimension overlaps with the response set required by the task. A centrally presented (say, upward) arrow influences the trajectory of a response even under passive viewing conditions (Kuhn & Kingstone, 2009), and when the task requires only left/right responses (Hermens & Walker, 2010). Thus, the effect of the arrow appears to be obligatory, and requires neither conscious attention, nor the intentional weighting of its spatial features to exert an effect on movement.

An UP/DOWN word like *eagle* (and presumably a spatial preposition like *up*) influences movement under passive viewing conditions, but this effect was observed only alongside the intention to engage in up/down responses (Experiment 3). In addition, semantic judgments of directionality trigger the spatial features of a preposition like *up* (Experiment 1) and of UP/DOWN words (Lebois et al., 2015). Some evidence indicates that UP/DOWN words also prime up/down movements when attention is directed to a non-spatial conceptual attribute, such as when judging whether or not the word refers to a concrete object (Lebois et al., 2015). Thus, subjects must either attend to meaning or must engage in up/down movements to trigger a spatial representation for UP/DOWN words; passive viewing alone is not sufficient (Experiments 1 and 3). Other sufficient conditions may exist, and we do not claim to have provided a complete list of sufficient conditions here. For example, Ansorge, Khalid, and Laback (2016) required subjects to classify a tone, coming from above or below the subject's head, as either "noisy" or "tonal" using a right or left keypress. The tone was preceded by a spatial word referring to an up or down location and presented with a mask that prevented conscious identification. Subjects were faster to classify the tone when the direction implied by the prime was congruent with the tone's location. In this case, primes were passively viewed, and subjects did not respond along a vertical axis, so what explains the effect? Because the tones were presented above or below the subject, it is possible that exogenous orienting of spatial attention along a vertical axis can also trigger spatial representations from spatial words.

Implications for embodied accounts of word meaning

Word meaning is dynamic and context dependent. For example, the sentence *A bird flew up the chimney* indicates movement in a particular direction whereas *I read up on embodied cognition* implies the gaining of some knowledge. The fact that understanding depends on context, and that spatial prepositions and UP/DOWN words do not automatically prime up/down movements (in that priming is task dependent rather than obligatory), might prompt a rejection of the idea that the meaning of a word includes a core semantic representation. Thus, according to Lebois et al. (2015): "...conceptual cores do not exist in word meanings... the spatial features of these words are dynamic and context-dependent, with their availability varying across task contexts. Many findings, across literatures, now demonstrate clearly that features potentially viewed as core are actually context-dependent" (pp. 1792–1793).

The fact that a spatial preposition like *up* has a variety of senses depending on context, however, does not exclude the possibility that these senses are connected by a unifying semantic device. In what follows, we discuss how the complex polysemy of *up* and *down* is grounded in what Tyler and Evans (2003) term a spatial "proto-scene", embodying the notion of verticality. We briefly provide some examples of how experiential correlations based on this proto-scene generate a number of meanings that are entirely non-spatial (see Tyler & Evans for many more ingenious analyses). We then apply this theoretical framework to clarify the nature of the influence that spatial prepositions and UP/DOWN words exert on vertical and horizontal movement.

The proto-scene for *up*, according to Tyler and Evans (2003), involves a background element as landmark (LM), conceptually partitioned into a top and bottom. A moving object or trajector (TR) is conceptualized as being oriented in an upward direction relative to the LM. These authors suggest that the human body itself is used to develop a schematization of the LM into top versus bottom, the head being our highest body part when we are standing upright (see Fig. 6). As they note, in a study of fifty-five languages, over half applied the word for head to indicate the spatial relation denoted by *up* (Svorou, 1994). When we say *the head of an organization*, we likewise draw upon the notion that the head is located at the top of the human body. The proto-scene for *down* stands in a contrastive relationship with *up*; it is now the lower half of the human body that is emphasized in the schematization of the LM, and the TR is oriented downward.

The sentence *A bird flew up/down the chimney* describes a TR (bird) oriented upward/downward in relation to a LM (chimney). The chimney is symmetrical in appearance, but has a vertical asymmetry projected onto it (i.e., we can refer to the top or bottom of a chimney). In addition to the meaning of *up* and *down* as directions, a cluster of meanings referring to quantity (e.g., *prices are going up/down*) is grounded in our experience that an increase/decrease in quantity correlates with an increase/decrease in vertical elevation (also see Lakoff, 1987). Moreover, a change in our posture from vertical to horizontal always requires a stable surface that halts our downward path; lying down implicates the end of a trajectory, so that down can also be taken to mean complete, as in *two down and one to go*.

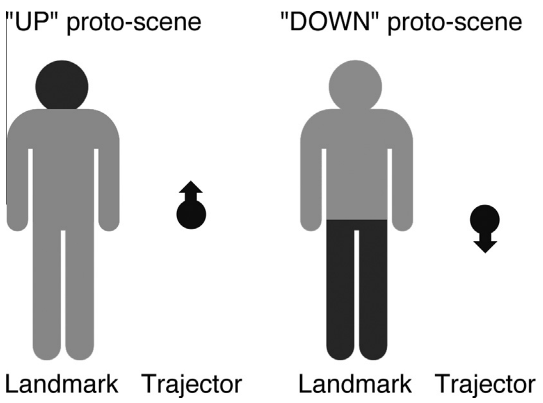

Fig. 6. Illustration of the spatial proto-scene, adapted from Figs. 6.1 and 6.2 of Tyler and Evans (2003).

We introduce the following ideas: The activation of an up or down proto-scene is directly responsible for the priming effect of a word or symbol on vertically oriented components of movement. An arrow pointing up or down automatically activates the corresponding proto-scene; the object is schematized as an upward or downward TR against a LM acting as background. The priming effect of an arrow on movement trajectories is therefore obligatory even when the task set does not include up/down movements.

Attending to the direction along a vertical axis implied by a spatial preposition also activates an up/down proto-scene. Thus, we find that directionality judgments on a spatial preposition acting as a prime affects the vertical component of a horizontal movement in Experiment 1. Any intentional (task) set of carrying out up versus down movements also enlists the corresponding proto-scenes which can then be triggered by an UP/DOWN word (and presumably by a spatial preposition) under passive viewing conditions (Experiment 3). However, in the absence of such conditions, neither spatial prepositions nor UP/DOWN words activate any proto-scene (Experiment 2).

Finally, an up/down proto-scene, even when induced by the task set of engaging in up/down movements, is not generally triggered by an emotionally valenced word like *happy* (feeling up) or *sad* (feeling down). Instead, the representation that gives rise to a priming effect on up/down movements requires an intentional set that codes up/down as functional elements having a positive/negative value, in accordance with our semantic representation of valence (*happy* is a positive feeling whereas *sad* is negative). Consistent with this claim, Ansorge et al. (2013) found no effect of subliminally presented positive or negative emotional words on the classification of spatial prepositions into up versus down categories. However, when the task required classifying emotional target words as positively or negatively valenced, reliable priming effects were induced by subliminal spatial words denoting an up/down direction or position. Thus, the valence of emotional words is primed by spatial words if the task set involves a recoding of up/down as spatial elements into functional elements with a positive or negative value. Unlike the spatial attributes of UP/DOWN words, however, valence is not triggered just by the intention to carry out an up/down movement.

Any embodied theory of meaning must give rise to testable predictions about the specific conditions under which words elicit spatial representations, and about the content of these representations. We have attempted to articulate the beginnings of such a framework here, using the concept of the spatial proto-scene, and we conclude by offering two predictions for future research. First, if the activation of an up/down proto-scene is responsible for the priming effect of an UP/DOWN word on the vertical component of a horizontal mouse movement, then the activation of such a proto-scene should result in priming effects of UP/DOWN words under passive viewing conditions, even in the absence of up/down movements. Given the assumption that an up/down arrow automatically evokes the corresponding proto-scene, a variation of our Experiment 2, in which a subset of the primes are replaced with up/down arrows, should result in spatial priming effects for the remaining word primes. A second prediction follows from our conjecture that representing the location of an object in terms of *up* or *down* is dependent on a schematization of the upright human body. Objects that are conceptualized as *up* are at head height or higher, objects that are construed as *down* are near or below our feet. Under the right task conditions, and given this anthropocentric viewpoint, the words *aeroplane* as well as *hat* will trigger the proto-scene for *up*, while *submarine* as well as *floor* will trigger the proto-scene for *down*. It follows that the magnitude of the priming effects should be insensitive to the degree of "up-ness" or "down-ness" implied by the UP/DOWN words. The word *submarine* should thus exert a priming effect no greater than *shoe*, for example.

We conclude by emphasizing the importance of the human body as a reference point for embodied theories of meaning. According to Wierzbicka (1985), the judgment of an object's relative size is often established by consulting our ability to pick it up with our hands. We have conjectured that representing the prototypical height of an object or its location in terms of up or down is similarly dependent on a schematization of the upright human body. Objects that are conceptualized as *up* are at head height or higher, objects that are construed as *down* are near or below our feet. The evocation of these spatial attributes, though not obligatory, is directly linked to our embodied perception of the world.

Acknowledgment

This work was supported by Discovery Grants from the Natural Science and Engineering Research Council of Canada awarded to D.N. Bub and to M.E.J. Masson.

Appendix A. Prime words

A.1. Experiment 1

UP: up, top, high, over
DOWN: down, bottom, low, under
NEUTRAL: crime, peace, honor, shame, joy, anger, victory, defeat

A.2. Experiment 2a and Experiment 3

UP: eagle, balloon, roof, ceiling, kite, airplane, peak, sun, summit, sky, plateau, north, height, top, crown, moon, tower, bird, star, cloud
DOWN: ground, earth, soil, foot, floor, cellar, ditch, street, carpet, worm, root, south, valley, canyon, under, puddle, stone, low, under, tunnel

A.3. Experiment 2b

UP: up, top, high, over
DOWN: down, bottom, low, under

Appendix B. Bayesian statistical analysis

B.1. Model for the AUC

For each subject i, we computed the area between the difference curve and the x-axis (denoted AUC_i) by integrating the trajectory using the trapezoid approximation. Due to the high pixel density of the display, AUC values are generally extremely large, making specification of a prior distribution difficult. For this reason, we scaled all AUC values by 1000 prior to analysis, producing values of roughly single digit magnitude.

Preliminary analysis revealed outlying AUC values which we could not justify excluding, as there was no evidence that these values were erroneous. Consequently, we estimated the mean AUC using a non-standardized t-distribution – selected as a robust alternative to the normal distribution, as the fat tails of a t-distribution allow it to accommodate a small number of outlying values. The non-standardized t-distribution is specified by three parameters: A location parameter μ, a scale parameter σ, and a degrees of freedom parameter ν, which governs the fatness of the tails. Note that the t-distribution does not have a mean (resp. variance) for $\nu \leqslant 1$ (resp. $\nu \leqslant 2$), and so caution must be used when interpreting μ and σ.

A weakly-informative $N(0,10)$ prior was selected for the location μ, in order to provide a small degree of regularization due to the outlying values. A Cauchy(0, 1) was placed on the scale σ^2, and an Exp(1) prior was placed on the degrees of freedom ν. The full model is thus

$$\begin{aligned} &\text{AUC}_i \sim t(\mu, \sigma^2, \nu) \\ &\mu \sim N(0,\,10) \\ &\sigma^2 \sim \text{Cauchy}(0,\,1) \\ &\nu \sim \text{Exp}(1) \end{aligned}$$

The model was fit by the Hamiltonian Monte-Carlo routine implemented in Stan 2.7 (Stan Development Team, 2015) using 3 chains of 1000 samples, of which the first 500 were discarded as burn-in. Convergence was assessed by verifying that the potential scale-reduction factor (Gelman & Rubin, 1992) was less than 1.1, and through visual inspection of the chains.

B.2. Model for the congruency effect in Experiment 3

We consider only initiation times for vertical (up/down) responses. Prior to analysis, we performed a median split of initiation times, and fit the model to short and long responses separately. For each subject i, we calculated the congruency effect θ_i by subtracting the mean initiation time in incongruent trials from the mean initiation time in congruent trials. We estimated the mean congruency effect by fitting a normal distribution to the effects θ_i. The model was as follows:

$$\theta_i \sim N(\mu, \sigma^2)$$
$$\mu \sim N(0, 100)$$
$$\sigma^2 \sim \text{Cauchy}(0, 15)$$

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